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Solubility of 2,3,7,8-TCDD (Tetrachlorodibenzo-p-Dioxin) in Contaminated Soils

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16. ABSTRACT:

Soils from ten sites contaminated with 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) were investigated in aqueous batch and intact core leaching studies to determine water/soil partition coefficients (K_p) for TCDD and factors affecting the K_p. TCDD content in soils ranged from 8 ng/g to 26,000 ng/g. For the batch extractions, TCDD concentrations in solution ranged from 0.1 ng/L to 56 ng/L; 79% of the values were 2.0 ng/L or less. For the intact cores, TCDD concentrations in leachate ranged from 0.1 ng/L to 14 ng/L; 81% of the values were 2.0 ng/L or less. K_p ranged from 0.3×10^5 mL/g to 130×10^5 mL/g with a mean of 18×10^5 mL/g. These indicate very low potential mobility in water percolating through soil.

TCDD solubility did not correlate strongly with clay and organic matter content in soil. Instead, both the amount of TCDD in the soil and the amount of TCDD in the water extracts were strongly related to the total solvent-extractable organic matter (SEOM) in soil and the halogenated semi-volatiles in the solvent-extractable fraction. SEOM of background (uncontaminated) soils was much lower than the contaminated soils. These results suggest that co-contaminants in the wastes along with the TCDD were sorbed to the soil and that these materials as a group greatly influence the partitioning of TCDD between soil and water in these contaminated soils.

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CHAPTER 13

Solubility of 2,3,7,8-TCDD in Contaminated Soils

D. R. Jackson, M. H. Roulier, H. M. Grotta, S. W. Rust, and J. S. Warner

INTRODUCTION

2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) has been associated with the manufacture of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), hexachlorophene, and other pesticides having 2,4,5-trichlorophenol as a precursor.[1] The persistence and toxicity of 2,3,7,8-TCDD have created concern on a national scale for the cleanup and safe disposal of contaminated soil.[2] The potential mobility of 2,3,7,8-TCDD in soil water is a factor in selecting remedial action alternatives for contaminated sites. Previous investigators[3-6] have documented that 2,3,7,8-TCDD is extremely immobile in most soils due to its low solubility in water (200 ppt).[7] For example, mobility of 2,3,7,8-TCDD in soils was limited to the upper 8 cm one year after an accident which contaminated a large area in Seveso, Italy.[8]

The octanol-water partition coefficient (K_{ow}) for hydrophobic compounds such as 2,3,7,8-TCDD is considered one of the most important physicochemical characteristics related to sorption on soils and sediments.[9] Hydrophobic compounds generally have log K_{ow}'s greater than 10[10] and are highly partitioned onto soils.[11] Dragun[12] has calculated the log K_{ow} for 2,3,7,8-TCDD to be equal to 7.16 using methods from Leo[13] and Hansch and Leo.[14] This value is in general agreement with the range of log K_{ow} values of 6.15-7.28 for 2,3,7,8-TCDD reported by the U. S. EPA.[15]

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Sorption of many hydrophobic compounds on soils and sediments has been related to the organic matter content of the sorbent and the K_{ow} of the hydrophobic compound.[10,16-20] The method generally employed in these studies is to determine a partition coefficient (K_p) over a broad range of aqueous concentrations. K_p is defined by,

$$K_p = \frac{X}{C} \quad (1)$$

where X denotes the concentration of the solute on the solid phase in ng/g;
C is the equilibrium solute concentration in ng/mL

Karickhoff et al.[19] found that individual K_p's determined for pyrene and methoxychlor on particle size isolates of three sediments were highly correlated with the organic carbon content of each particle size fraction. A single partition coefficient (K_{oc}) was determined to describe partitioning for all the soil particle size fractions by normalizing the K_p of each fraction for its organic matter content. The following formula describes this relationship.

$$K_{oc} = K_p/f_{oc} \quad (2)$$

where K_{oc} is the organic carbon partition coefficient
f_{oc} is the fractional mass of organic carbon in the sediments

Karickhoff et al.[19] extended this relationship using ten hydrophobic compounds to relate K_{oc} to K_{ow} using the linear regression equation

$$\log K_{oc} = \log K_{ow} - 0.21 \quad (3)$$

Hassett et al.[10] confirmed these sorption relationships using dibenzothiophene (an unchlorinated dioxin-like compound) and 14 soil and sediment samples.

Previous investigations of 2,3,7,8-TCDD sorption have been conducted under idealized conditions; 2,3,7,8-TCDD has been spiked as a single compound on uncontaminated soil, the soil mixed with water, and a partition coefficient calculated from measurements of the amount of 2,3,7,8-TCDD in solution. These experimental conditions may not address the chemical and physical reactions of 2,3,7,8-TCDD that occur over an extended time period in the soil environment, particularly when 2,3,7,8-TCDD is a trace contaminant in a complex mixture of other organic chemicals that have been applied to the soil.

This report examines the sorption behavior of ten soils contaminated with 2,3,7,8-TCDD more than ten years ago. The objectives of this investigation were to determine water/soil partition coefficients (K_p) for 2,3,7,8-TCDD and analyze relationships between K_p values and soil physicochemical parameters.

SITE HISTORY

Samples of contaminated soils were collected from Missouri and New Jersey. The Missouri samples were collected from two horse arenas, two residential sites, and four sites adjacent to roadways. These sites, listed in Table 1, were contaminated with 2,3,7,8-TCDD as a result of being sprayed with various mixtures of waste oil. While no official records are available on the chemical composition of these oily mixtures, investigations by the St. Louis Post-Dispatch[21] indicate that waste crankcase oil was often sprayed in addition to chemical still bottoms containing 2,3,7,8-TCDD and waste transformer oil which contained PCBs. These materials were applied on soils to control dust.

The soil sample from the slough area at Shenandoah Stables contained the highest level of 2,3,7,8-TCDD (2,400 ng/g) in soil collected from Missouri. Soil from this site was collected from a deposit of contaminated soil which had been scraped from the adjacent indoor arena. A second horse arena was sampled at Bubbling Springs Stables. This outdoor arena also had been scraped to remove visibly contaminated soil prior to any knowledge of the presence of 2,3,7,8-TCDD on the site. According to the St. Louis Post-Dispatch[21] investigation, material from this arena was deposited at the Minker residence as fill material to prevent erosion. Two samples from the Minker residence were collected (Table 1). These samples were higher in 2,3,7,8-TCDD concentration than the one collected from the Bubbling Springs Stables. This observation is representative of the fact that soil deposited at the Minker site originated from the more highly contaminated surface layers of the arena at Bubbling Springs Stables.

Two soil samples were collected adjacent to Piazza Road (Table 1). These samples, although located within one-half mile of each other, varied in 2,3,7,8-TCDD concentration by approximately fivefold. Samples from Sontag Road and Times Beach, both adjacent to residential streets, represent the lowest 2,3,7,8-TCDD concentrations from locations in Missouri known to have been sprayed with contaminated oil. Due to the inherent variability expected in soil 2,3,7,8-TCDD concentrations as a result of oil spraying, samples collected for this investigation may not be representative of the overall contamination level at each of the sites.

Samples were collected from two different locations at the Minker residence and at the Piazza Road site because enough data were available from previous work at these sites to identify areas with high and low levels of 2,3,7,8-TCDD contamination. The two samples from each location differed considerably in 2,3,7,8-TCDD concentration (Table 1); this facilitated the statistical analysis of the relations between soil properties and partition coefficients (K_p).

The soil sample containing the highest concentration of 2,3,7,8-TCDD (26,000 ng/g) was collected from a defunct chemical manufacturing plant in

Table 1. Physical and Chemical Properties of Soils.

No.	Location	Site	Total 2,3,7,8-TCDD Concentration	SEOM[a]	Peak Area[b]	Organic Carbon	CEC[c]	pH	EC[d]	Sand	Silt	Clay	Texture
1	New Jersey	Chemical Plant	26,000	22	270	8.0	13	7.5	65	81	18	1	Loamy Sand
2	Missouri	Shenandoah Stables[e]	2,400	7.1	15	6.0	39	7.3	195	42	52	6	Silty Loam
3	Missouri	Piazza Road-1	1,100	5.2	2	2.7	35	6.7	95	57	30	12	Sandy Loam
4	New Jersey	Scrap Yard	1,100	19	21	3.7	18	6.7	99	72	23	5	Sandy Loam
5	Missouri	Minker-2	760	5.3	4	2.5	24	7.7	139	34	59	7	Silty Loam
6	Missouri	Minker-1	610	7.0	4	2.2	19	8.0	119	56	37	7	Sandy Loam
7	Missouri	Bubbling Springs Stables	280	3.4	2	1.5	13	7.6	101	61	37	2	Sandy Loam
8	Missouri	Piazza Road-2	230	0.7	0.6	7.6	54	7.5	153	60	30	9	Sandy Loam
9	Missouri	Sontag Road	63	5.2	0.7	6.0	37	8.4	350	38	58	3	Silty Loam
10	Missouri	Times Beach	8	0.3	0.4	1.7	23	7.7	107	52	43	4	Sandy Loam

[a]Solvent-extractable organic matter.
[b]Total peak area of solvent-extractable chlorinated organic compounds detected by GC-ECD analysis.
[c]Cation exchange capacity.
[d]Electrical conductivity.
[e]From slough area.

New Jersey. A second sample was collected from a nearby metal scrap yard where used reactor vessels from the chemical plant were collected and disassembled. A soil concentration of 1100 ng/g was found at this site. Contamination of 2,3,7,8-TCDD at these two sites, which occurred between 1968 and 1971, represents spillage of 2,4,5-trichlorophenol (2,4,5-TCP) still bottoms from the manufacture of certain chlorinated pesticides and 2,4,5-T.

MATERIALS AND METHODS

One background soil sample was collected outside each of the contaminated areas at Shenandoah Stables, Piazza Road, Bubbling Springs Stables, Sontag Road, and Times Beach. These samples were analyzed for 2,3,7,8-TCDD to confirm that they were uncontaminated (less than 1.0 ng/g). These soils were analyzed for solvent-extractable organic matter (SEOM) as a basis for estimating the amounts of organic contaminants (other than 2,3,7,8-TCDD) in SEOM from the contaminated samples. These background samples were not used in any other phase of this study.

Bulk soil samples were collected by excavating soil to a depth of approximately 15 cm. The soil was mixed and placed in plastic-lined 5-gal steel containers. These samples comprised a variety of physicochemical characteristics (Table 1) and total 2,3,7,8-TCDD concentrations (Figure 1). Soil pH was determined using a soil-to-water ratio of 1:1.[22] Electrical conductivity (EC) was measured using a suspension of soil and water mixed in a ratio of 1:2.[23] Soil organic carbon content was determined by oxidation with $K_2Cr_2O_7$ and colorimetry.[23] Cation exchange capacity (CEC) was based on soil saturation with NH_4^+ followed by displacement with K^+; analysis of displaced NH_4^+ was conducted using an ammonium ion-specific electrode.[24] Particle size analysis (sand, silt, and clay content) was conducted by the hydrometer method.[25]

Soil Extracts

The analytical method for determining 2,3,7,8-TCDD in soil extracts required a sample volume of 1 L. Therefore, a procedure for generating soil extracts was selected to accommodate this requirement. A batch extraction procedure was used to determine the effect of sequential extraction on the partitioning of 2,3,7,8-TCDD between soil and water.[26] This method is similar to the Standard Leaching Test (SLT) developed by Ham et al.[27] For this procedure, two 100-g aliquots from the contaminated soil sample for each location were sequentially extracted twice with 1 L of distilled water by tumbling for 18 hr at 30 rpm using an electric-powered rotary extractor. The 18-hr extraction time was used to facilitate efficient laboratory operations and to minimize biological activity which a longer equilibration time

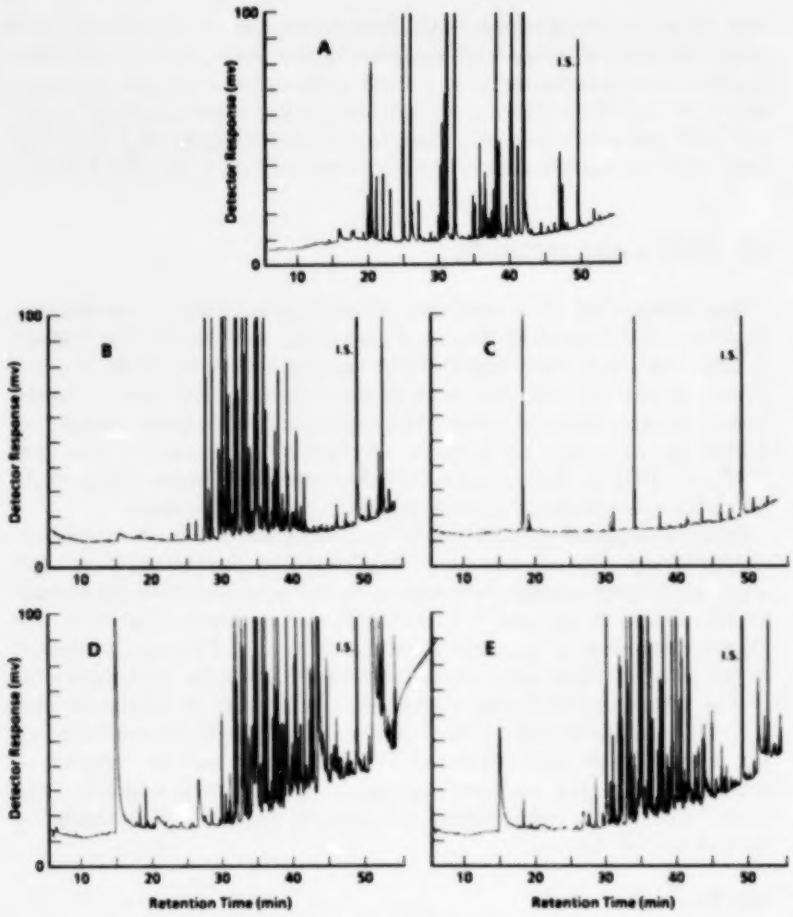

Figure 1. Gas chromatogram obtained in analysis of solvent extracts of five contaminated soils; (A) Chemical plant, (B) Shenandoah Stables, (C) Piazza Road-2, (D) Minker-2, and (E) Bubbling Springs Stables. I.S. refers to the internal standard (octachlorobiphenyl).

would encourage. Due to this time constraint, the partition coefficients resulting from this method are not necessarily representative of equilibrium conditions in the soils evaluated. Kinetics of 2,3,7,8-TCDD desorption from soil were not within the scope of this investigation. The suspensions were placed in pressurized filtration vessels and filtered through Millipore hydrophilic cellulose acetate and nitrate membranes with a pore size of 0.45

μm. The filtrates were analyzed for 2,3,7,8-TCDD content. Each 100-g aliquot of contaminated soil was extracted a second time by repeating the above procedure. This procedure results in leachates representing two sequential extractions of each of two 100-g aliquots of each soil sample. Each extract was analyzed for 2,3,7,8-TCDD using a modified version of the U. S. EPA Region VII protocol.[28]

Solvent-Extractable Organic Matter

Solvent-extractable organic matter of soils was determined by extracting a suspension of 30 g of soil in 30 mL of an aqueous solution containing 30% NaCl and 2% KH_2PO_4 with 30mL of methyl tert-butyl ether (MTBE).[29] Extraction was facilitated by mixing the soil-liquid suspension for 18 hr using a tumbling apparatus. The MTBE phase was separated from the aqueous phase using a separatory funnel. The MTBE layer was dried with 2 g of anhydrous $MgSO_4$. The dried MTBE extract was filtered through a 0.5-μm PTFE membrane filter. A 100-μL aliquot of the filtered extract was transferred to a tared aluminum weighing dish, evaporated to dryness under a heat lamp, and reweighed using a microbalance to determine the weight of low-volatility organic compounds. This method is suitable for the extraction of most phenols, anilines, and neutral semivolatile organic compounds. SEOM values determined for the contaminated soils are presented in Table 1.

Gas Chromatography Analysis of Solvent Extract

The MTBE extract of soil was analyzed by gas chromatography (GC) using a fused-silica capillary column and a ^{63}Ni electron capture detector (ECD). The GC conditions used were the following.

Column: 30 m × 0.25 mm i.d., 0.25 μm film thickness, J&W DB-5
Column temperature: 80 to 300°C at 4°/min, 300°C for 10 min
Injector temperature: 250°C
Detector temperature: 350°C
Carrier gas: helium at 30 cm/sec
Makeup gas: nitrogen at 30 mL/min
Injection: 2μL splitless.

The combined GC-ECD peak area of all chromatographic peaks eluting after 5 min, referred to as peak area in Table 1, was obtained using a computerized integration and data processing system. The combined peak area response was used as an indicator of the total amount of chlorinated semivolatile organic compounds present. Although the electron capture detector detects a variety of compounds other than chlorinated compounds, e.g., brominated compounds, nitro compounds, and phthalates, chlorinated compounds were expected to account for the majority of the electron capture response from the extracts generated in this study.

RESULTS AND DISCUSSION

Soil Properties

Soil 2,3,7,8-TCDD levels ranged from 8 to 26,000 ng/g (Table 1). Missouri samples as a group were lower in 2,3,7,8-TCDD content than those from New Jersey. This difference reflects two sources of soil contamination. The New Jersey soils were contaminated by leakage from 2,4,5-TCP reactor vessels or storage tanks, while samples from Missouri were contaminated by spraying with still bottoms diluted with used oil.

Soil organic carbon content ranged from 1.5 to 8.0% (Table 1). This wide range in organic carbon content produced a greater basis for the regression of this parameter versus K_p values. Solvent-extractable organic matter (SEOM) content ranged from 0.3 to 22 mg/g in the contaminated soils. This parameter ranged from 0.5 to 1.5 mg/g in background soils collected from sites in Missouri. Seven of the ten soil samples included in this study had SEOM values greater than background levels. This parameter represents the concentration of organic compounds which are soluble in a moderately polar organic solvent and relatively insoluble in water. The peak area of chlorinated semivolatile organic compounds for the soils ranged from 0.4 to 270. Peak area and SEOM were considered indicative of the relative concentrations of cocontaminants which were presumably applied to the soil as a mixture with 2,3,7,8-TCDD.

Selected GC-ECD chromatograms are presented in Figure 1. Although specific compounds were not identified, considerable differences were apparent in the chromatographic patterns obtained from these soils. The chemical plant soil contained a variety of discrete compounds distributed throughout the midrange of the chromatogram. The soil from Shenandoah Stables, Minker, and Bubbling Springs Stables gave chromatographic patterns indicative of a polyhalogenated mixture such as a polychlorinated biphenyl (PCB). The chromatographic patterns from the Minker and Bubbling Springs Stables soils are nearly identical, and represent a somewhat higher degree of chlorination than that from the Shenandoah Stables soil. The soil from Piazza Road-2 was nearly devoid of chlorinated components, even though this sample was relatively high in 2,3,7,8-TCDD. Electrolyte concentration as determined by EC in soil leachate (Table 2) was reduced 51% in the second leaching of the SWLP-R relative to the first fraction. Soils exhibiting this general trend contained the greatest levels of 2,3,7,8-TCDD and halogenated organic content as determined by peak area (Table 1). These results imply that the lower electrolyte level of the second extract allows a higher concentration of 2,3,7,8-TCDD to come into solution. These observations are supported by Karickhoff,[30] who discussed a relationship between solution electrolyte concentration and solubility of hydrophobic compounds.

Table 2. Electrical Conductivity (EC) of Soil Leachates.

Site Number	EC (μmhos/cm)	
	Extract 1	Extract 2
1	30.8	15.6
2	76.5	31.0
3	47.8	22.4
4	32.1	17.1
5	93.4	43.2
6	78.1	40.3
7	59.7	31.8
8	119	74.3
9	171	74.1
10	76.6	44.5
Mean	78.5	40.3

Soil Leachates

The 2,3,7,8-TCDD concentration in aqueous soil extracts ranged from 0.1 ng/L to 55 ng/L; 73% of the concentrations were 2.0 ng/L or less. The greatest concentration of 2,3,7,8-TCDD in soil extracts, 55 ng/L (Figure 2), was found in the second leaching fraction of the extraction procedure for the chemical plant soil and represented a tenfold greater concentration than the first leaching fraction. Relatively greater concentrations of 2,3,7,8-TCDD were found in the second leaching fraction of the batch procedure in six of the ten soils analyzed. Soils exhibiting this general trend contained the greatest levels of 2,3,7,8-TCDD and chlorinated organic content as determined by peak area (Table 1).

Additional information on leachability of 2,3,7,8-TCDD from the Missouri and New Jersey soils using intact cores and another batch procedure has been reported recently.[31]

Soil Partition Coefficients

A soil partition coefficient (K_p) was computed using Equation 1 for soil extract produced by the batch extraction method. The coefficients, presented in Figure 3, ranged from 0.4×10^5 to 45.8×10^5, with an overall mean of 9.6×10^5.

Log K_{oc} values were computed for each soil using Equation 3. Values of log K_{oc} were computed in order to make comparisons between these values and those predicted from Equation 3 using the log K_{ow} of 7.16 provided by Dragun.[12] The log K_{oc} for 2,3,7,8-TCDD predicted by this method is 6.95. The mean log K_{oc} value determined from experimental K_p values using Equation 3 for the batch extraction procedure was 7.39, which was within one standard deviation of the predicted value.

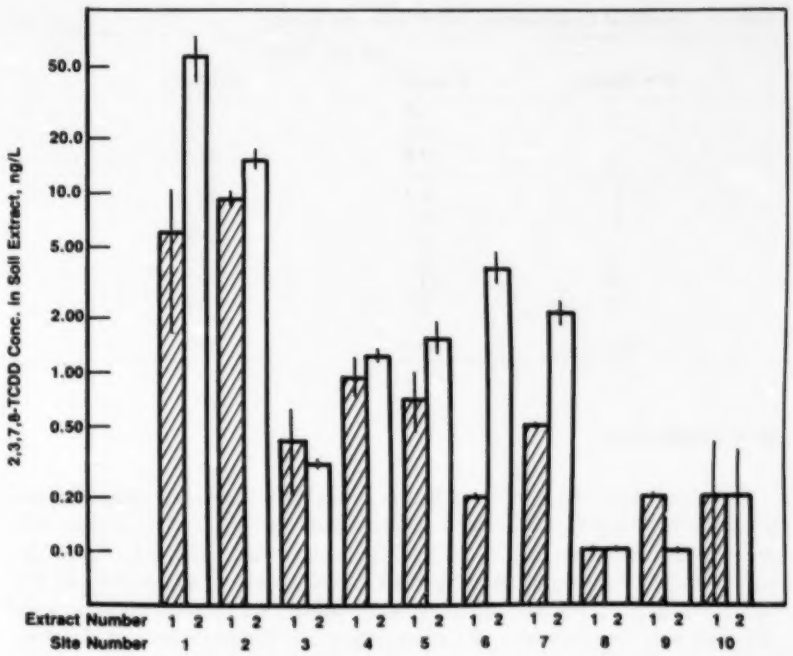

Figure 2. Concentrations of 2,3,7,8-TCDD in soil leachates from ten contaminated soils.

Statistical Analyses

Correlation and regression analyses were used to investigate relationships between the soil property variables (independent variables) presented in Table 1 and the concentrations of 2,3,7,8-TCDD in soil extracts and soil partition coefficients (dependent variables) presented in Figures 2 and 3. The soil property variables were not experimentally manipulated to assess their effect on the dependent variables. However, the soils used in the study exhibited a sufficiently wide range of chemical and physical properties (Table 1) that correlation and regression analyses yielded information about the effect of soil properties on partition coefficients and 2,3,7,8-TCDD concentrations. Results of the correlation and regression analyses were used to develop hypotheses about mechanisms involved in 2,3,7,8-TCDD solubility in contaminated soils. Only soils from Missouri were included in the statistical analyses because most of the data were from Missouri, and because of the differences in soil type and pattern of contamination between the Missouri and New Jersey sites.

The correlation matrix presented in Table 3 was constructed to examine

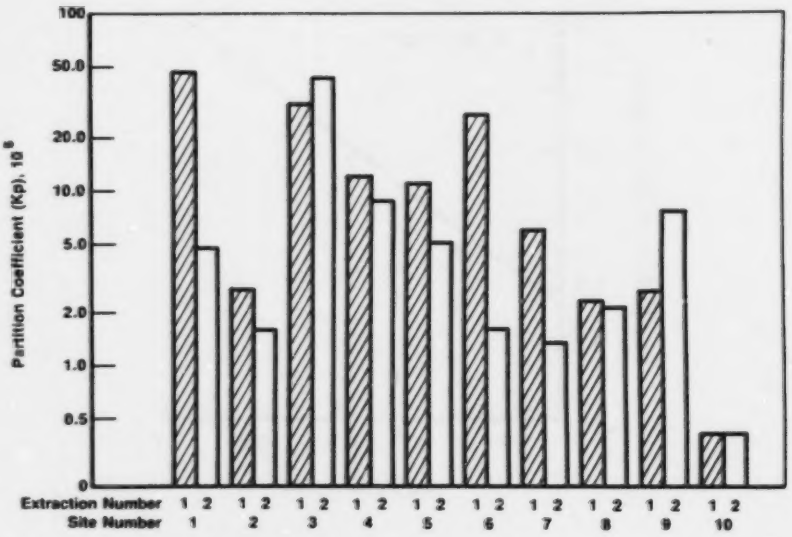

Figure 3. Partition coefficients (K_p) obtained from ten contaminated soils.

the significance of relationships between selected soil property variables and dependent variables. Observed significance levels (OSLs), which indicate the significance of the reported correlation coefficients, are provided in parentheses. For example, an OSL value of 0.05 indicates that the corresponding correlation coefficient is significantly different from zero at a confidence level of 95%.

The log soil concentration of 2,3,7,8-TCDD was positively correlated with the leachate concentrations. However, the leachate concentrations were most highly correlated with the log peak area parameter. The relationships between log peak area and the soil and extract 2,3,7,8-TCDD concentrations are illustrated graphically in Figure 4. These figures are log-log plots of 2,3,7,8-TCDD concentration versus peak area. The least squares regression line has been superimposed on each plot. The intercept, slope, percentage of explained variation, and observed significance level for each regression line are provided in Table 4. These relationships imply that chlo-

Table 3. Correlation Matrix for Soil Property Variables Versus TCDD Concentrations in Bulk Soil and Soil Extracts and K_p Values.[a]

Dependent Variable	Log 2,3,7,8-$TCDD_{Soil}$	$Log_{PeakArea}$	Log (SEOM)	% Organic Carbon
Log 2,3,7,8-$TCDD_{Soil}$		0.84 (0.01)	0.76 (0.03)	0.14 (0.74)
Log 2,3,7,8-$TCDD_{Extract}$	0.66 (0.08)	0.95 (0.00)	0.61 (0.11)	–0.16 (0.71)

[a]Observed significance levels in parentheses.

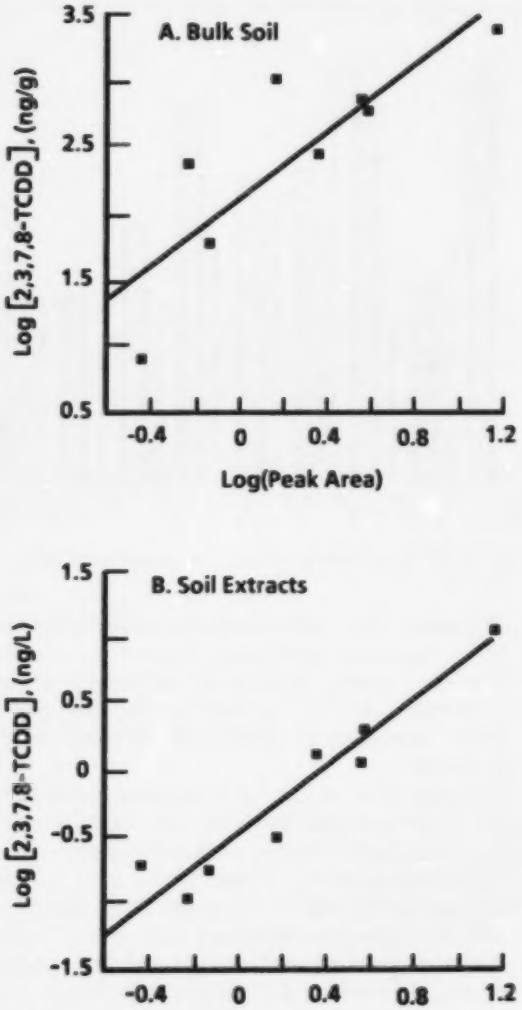

Figure 4. Log-log plots of 2,3,7,8-TCDD concentrations in soil and soil leachates versus peak area for eight contaminated soils from Missouri.

rinated semivolatile organic compounds were cocontaminants in the waste applied to these soils and may be a most important determinant for the relative aqueous extractability 2,3,7,8-TCDD in the Missouri soils.

This effect of the cocontaminants is most strikingly illustrated by com-

Table 4. Least Squares Regression Analysis of $Log_{2,3,7,8\text{-TCDD}}$ Versus $Log_{Peak\ Area}$

Dependent Variable	Intercept	Slope	R^2	Observed Significance Level
Log 2,3,7,8-$TCDD_{Soil}$	2.14	1.26	0.70	0.01
Log 2,3,7,8-$TCDD_{Leachates}$	−0.49	1.25	0.91	0.00

paring the results from Bubbling Springs and Piazza Road-2. These soils contain comparable amounts of 2,3,7,8-TCDD (234 and 275 ng/g). Bubbling Springs has much greater amounts of cocontaminants (compare Figure 1-C and Figure 1-E) and the 2,3,7,8-TCDD concentrations in aqueous soil extracts from Bubbling Springs were about twice as great as those from Piazza Road-2, even though both soils contained comparable amounts of 2,3,7,8-TCDD.

The relationship between soil organic carbon content and the K_p values for the eight soils was investigated to determine the significance of computing K_{oc} values for the soils. The partition coefficients for these contaminated soils were not significantly related to soil organic matter content ($r = 0.36$). Thus, normalization of the K_p values for soil organic carbon content did not reduce the variability associated with the nonnormalized K_p values.

SUMMARY AND CONCLUSIONS

Log K_{oc} values based on the 2,3,7,8-TCDD concentration in bulk soil and soil leachates and soil organic carbon content were determined for ten contaminated soils from Missouri and New Jersey. The calculated mean log K_{oc} value of 7.39 was within one standard deviation of a predicted value of 6.95. The log K_{oc} parameter is based on a linear relationship between K_p and soil organic carbon content.[19] This relationship was not apparent for the soils analyzed in this investigation. However, a strong association was found between 2,3,7,8-TCDD concentration in soil extracts and log GC-ECD peak area of organic solvent extract. This relationship suggests that the relative aqueous extractability of 2,3,7,8-TCDD in these soils is regulated primarily on the basis of soil levels of organic solvent-extractable chlorinated compounds. This conclusion is compatible with the theory that bonding of hydrophobic compounds in soil is analogous to partitioning of the compounds between water and immiscible solvent.[29]

Studies by Karickhoff et al.[19] and Hassett et al.[10] are based on partitioning of hydrophobic compounds between initially clean soils and aqueous solutions containing only the hydrophobic compound. In these cases indigenous organic matter is the most compatible substrate in the soil matrix for sorption of the hydrophobic compounds.

Conditions in the soils used in this study were considerably different than

those in the studies cited above. The 2,3,7,8-TCDD applied to the soils from the Missouri region is alleged to have originated from chemical still bottoms which would most likely contain chlorinated benzenes and trichlorophenols. These still bottoms were generally mixed with used engine crankcase oil and possibly transformer oil prior to soil application. Soil contamination at the New Jersey sites can be attributed primarily to storage tank leakage of still bottoms from pesticides manufacturing. In both cases chlorinated and other organic compounds which are insoluble in water and resistant to soil microbial degradation were added to the soil as cocontaminants. We conclude that these organic compounds are sorbed to the soil matrix, and that these chlorinated compounds as a group greatly influence the partitioning of 2,3,7,8-TCDD between the soil solid-phase and soil water extracts in the contaminated soils.

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